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**IMPACT OF DREDGING ON DUNGENESS CRAB,
CANCER MAGISTER, IN GRAYS HARBOR,
WASHINGTON, DURING AUGUST 1989**

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EXECUTIVE SUMMARY

1. Dredge entrainment and trawl samples of Dungeness crab were taken at five stations within the Grays Harbor Navigation Channel. Forty-two trawls yielded a total of 2637 crab; 570 30-second entrainment samples contained 252 crab.
2. Average trawl catch of Dungeness crab at the 5 stations ranged from 502 to 1530 crab·ha⁻¹. Crab entrained by the dredge ranged from 40 to 325 crab·kcy⁻¹ (49 to 352 crab·ha⁻¹).
3. About 70% of crab caught by both methods were males. This might be attributed to emigration of females from the estuary at an earlier age than males.
4. Size composition of the catch was significantly different for the two gears. The differences may be attributable to several factors. Size composition was similar at the four outer stations (1, 1.5, 2, and 3); more small crab were caught at the innermost station (3.5).
5. Only one age group (0+) could be identified in the catch. This age class comprised 14.1% of the trawl catch and 21.7% of the measurable entrainment catch. The percentage of 0+ crab in the four outer stations ranged from 4.6% to 21.7%, but was 56.6% at the innermost station. This difference is attributable to habitat variation within the Navigation Channel.
6. A linear regression of entrainment catch on trawl catch based on 14 data points from four entrainment studies yielded the relationship
$$Y = 0.27X,$$
where Y is entrainment by the dredge (crab·kcy⁻¹), and X is trawl catch (crab·ha⁻¹).
7. Broader-scale trawl sampling throughout Grays Harbor yielded an overall population estimate (assuming 100% gear efficiency) of 9.98 (±3.59) million crab, with average densities ranging from 725 to 2070 crab·ha⁻¹ across the sampling strata. Age 0+ crab comprised over 50% of the population. In comparison, crab densities in the Navigation Channel were similar to those in the estuary as a whole, but crab caught in the Channel were generally larger (older).

INTRODUCTION

Grays Harbor has been an important shipping center for the lumber industry since the late 1800s, and has required deepening and stabilization of the harbor entrance and navigation channels. Dredging began in 1905, and an average of 1.5-1.7 million cubic yards (cy) is removed annually for channel maintenance. In 1987, Congress approved funds for a new "Widening and Deepening" (W&D) project for Grays Harbor, which would require removing 11.3 million cy of sediment, and would increase annual maintenance dredging to between 2.4 and 2.8 million cy (about 770,000 cy above present amounts). This project is being undertaken by the Seattle District, U.S. Army Corps of Engineers (COE), and the Port of Grays Harbor, the local sponsor.

Important commercial and sport fisheries for Dungeness crab (*Cancer magister* Dana) have existed in and near Grays Harbor since the early 1900s (Cleaver 1949). Studies by the Washington Department of Fisheries suggested that Grays Harbor was also a nursery area for juvenile crab (Tegelberg and Magoon 1970), a notion substantiated by Stevens and Armstrong (1984), Armstrong and Gunderson (1985), and Gunderson et al. (1989). Studies have also shown that substantial numbers of crab were entrained and killed by maintenance and other dredging operations (Tegelberg and Arthur 1977; Stevens 1981; Armstrong et al. 1982).

Because of the expected entrainment and loss of Dungeness crab during the W&D project, COE is investigating methods to reduce impacts on the crab resource. Joint studies have been conducted by the Seattle District COE and the University of Washington School of Fisheries (SOF) in Grays Harbor in October 1985, August 1986, and August 1987 (Dinnel et al. 1986a, 1986b; Dumbauld et al. 1988; McGraw et al. 1988). During these studies, the COE monitored crab entrainment aboard the Corps' hopper dredge YAQUINA, while the SOF conducted trawl sampling to assess crab abundance in the areas being dredged. Results of these studies provided estimates of absolute entrainment rates that ranged from 46 to 500 crab per thousand cubic yards (kcy) dredged, showed variable local crab density (from 504 to 1561 crab-ha⁻¹, based on trawl estimates), demonstrated no detectable effect of modifying the dredge draghead to exclude crab, and provided data for entrainment-versus-density curves that served as the basis of a crab entrainment model (Armstrong et al. 1987).

This report represents a continuation of these studies, detailing a joint SOF-COE entrainment study conducted during August 1989. The objective of the 1989 work was to refine our understanding of the relationship between dredging entrainment and local crab abundance, via the following tasks:

1. Conduct trawl surveys and dredge entrainment sampling at five stations within the Grays Harbor Navigation Channel.
2. Determine the size and sex of crab caught.

3. Compare the relative numbers of crab caught by the two sampling methods, as well as the size and sex composition of the catch.
4. Conduct trawl surveys at previously sampled stations throughout Grays Harbor to assess overall crab abundance.

MATERIALS AND METHODS

Sampling was conducted simultaneously by two different methods. Entrainment sampling was conducted on board the COE hopper dredge YAQUINA by diverting dredged material through screening baskets before the material entered the hopper. Trawl samples were taken from the fishing vessel KARELIA (Westport, WA) in the same sections of channel as the entrainment samples.

Sampling by both methods was conducted at five stations in the Grays Harbor Navigation Channel (Figure 1). Four of these stations (1, 1.5, 2, and 3) were sampled during previous studies; the fifth (3.5) was added to provide more comparative information for the outer harbor. Two stations sampled during previous work (4 and Bar) were excluded because of severe sampling problems.

ENTRAINMENT SAMPLING

During sample collection aboard the YAQUINA, half of the dredged material from both dragheads was diverted into collection baskets by means of a specially designed distribution system (Figure 2). The other half of the material went directly into the dredge hopper. Sampling duration was 30 seconds, the optimal time established from previous studies. At least 100 samples were taken at each station. All crab caught were measured, sexed, and evaluated for injury on a scale of 1 to 3: 1 was excellent condition, 2 indicated fair condition (e.g., a missing leg), and 3 represented an obviously dead crab or one that sustained an injury judged to be lethal (e.g., cracked or mutilated carapace, or absence of both chelae).

TRAWL SAMPLING

Samples were taken on the KARELIA with a 3-m plumb staff beam trawl (Gunderson and Ellis 1986) with an effective fishing width of 2.3 m. Tow lengths ranged from 200 to 300 m (corresponding to areas swept of 460 to 690 m²), with durations of 5 to 13 minutes. All trawls were conducted on 19, 20, and 21 August 1989. Because previous surveys (Dinnel et al. 1986a,b) showed no effect of dredging on trawl catches, trawling was conducted independent of the dredge. All Dungeness crab from each trawl were counted, sexed, measured, and returned live to the general area of capture. All fish were counted by species, and lengths were measured for the most

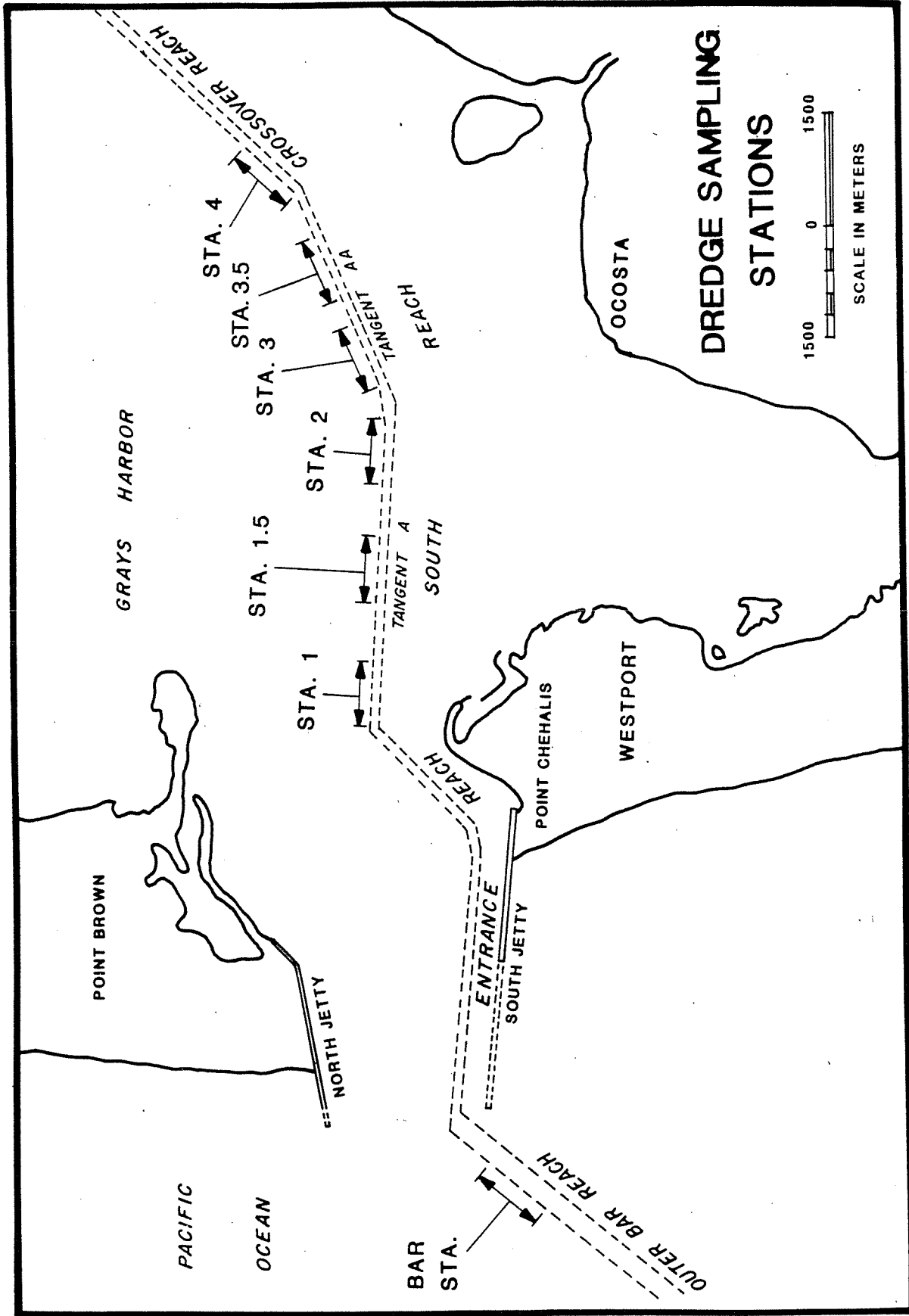


Figure 1. Chart of Grays Harbor Navigation Channel, showing sampling stations for this and previous entrainment studies.

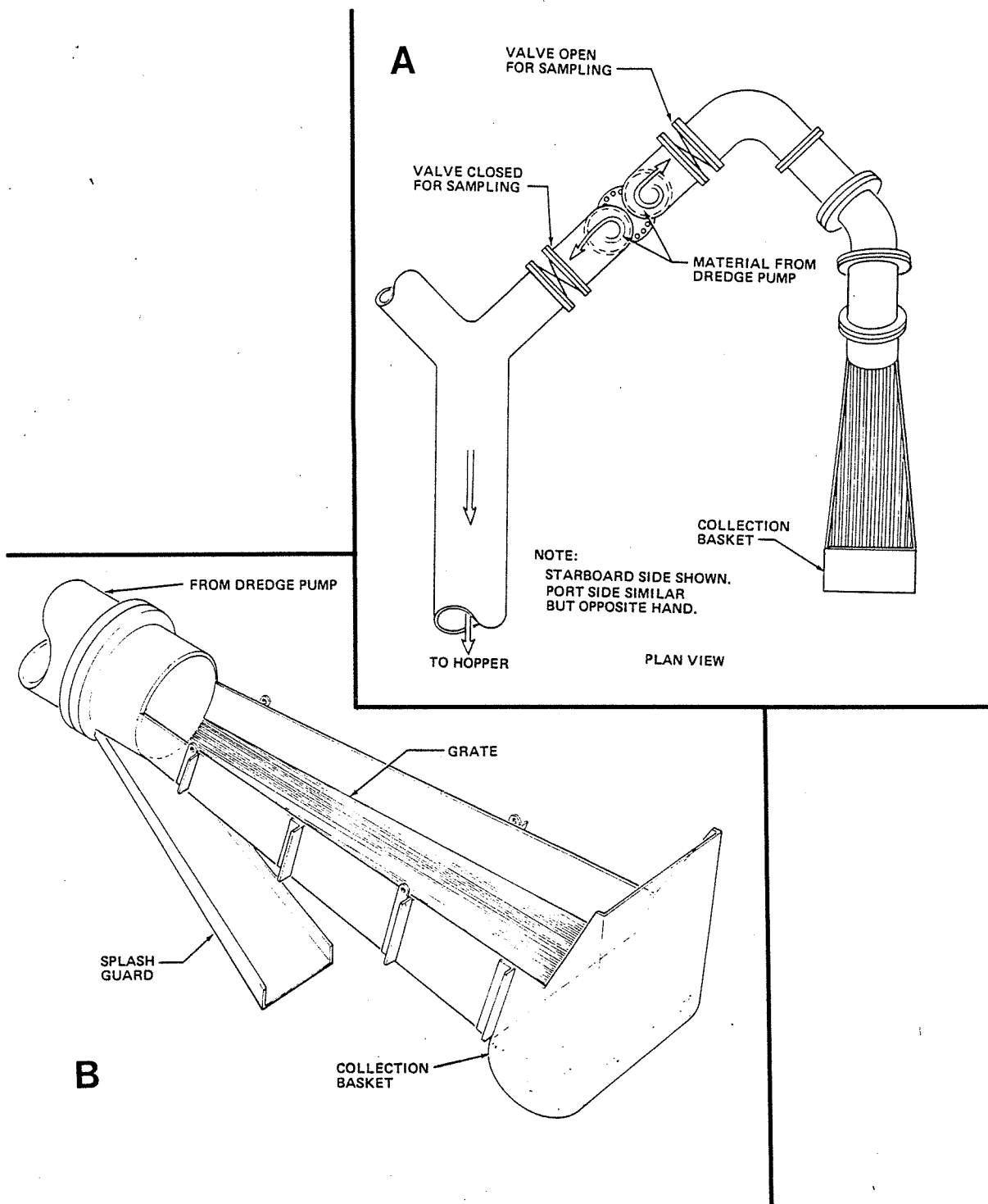


Figure 2. Sampling gear aboard the dredge YAQUINA. A—system for diverting sediment stream into collection basket; B—detail of collection basket.

common species. Surface and bottom water samples were collected from each station, and temperature and salinity were recorded.

In addition to trawling at the dredge stations, Dungeness crab sampling was conducted at 18 stations in 4 areas of the estuary (Figure 3). Stations sampled were the same as those used during a previous crab study funded by Sea Grant (Armstrong et al. 1986, 1987; Gunderson et al. 1985, 1989). Data from these samples were used to compute crab population estimates for the estuary.

DATA ANALYSIS

Trawl catches were converted to density estimates on an area swept basis:

Density = Catch / Area swept, where

Area swept (ha) = distance (m) x net width (m) / 10,000

Although gear efficiency is probably not 100%, this calculation assumes that the trawl catches all of the crab in its path because we have no reliable measure of the actual sampling efficiency of the gear in Grays Harbor.

Crab density from dredge samples was calculated on a volumetric basis (crab·kcy⁻¹ of dredged material) and also on an area swept basis. The loading rates were recorded from instruments on the bridge of the YAQUINA during sampling and averaged about 10 cy·min⁻¹ for each draghead, or a total of 20 cy·min⁻¹ for both.

The area swept by the dragheads of the hopper dredge was calculated using information provided by the COE regarding the effective dredging width of the draghead when stationary (i.e., 1.5 x width of the draghead) and instantaneous readings of speed over ground during sampling. The dragheads of the YAQUINA are each 1.2 m in width; therefore, the effective dredging width is 1.5 x 1.2 m = 1.8 m. The area swept by one draghead is obtained by the following:

Area swept (m²) = 1.8 x Distance traversed (m).

Speed over ground averaged about 1 knot (ca. 2 km·h⁻¹) during sampling.

The mean numbers of crab·kcy⁻¹ and crab·ha⁻¹ from dredge samples at each of the five stations were calculated and compared with mean crab densities (in crab·ha⁻¹) from trawls at those stations. The correlation of crab·kcy⁻¹ for the dredge samples and crab·ha⁻¹ for the trawl samples is the more important of the two density comparisons because of its use in revising the crab impact model (Armstrong et al. 1987), upon which future mitigation efforts will be based.

Most data analyses were performed using spreadsheet programs (Lotus 1-2-3 and Microsoft Excel) on desktop computers. Population estimates from the Sea Grant station data were computed

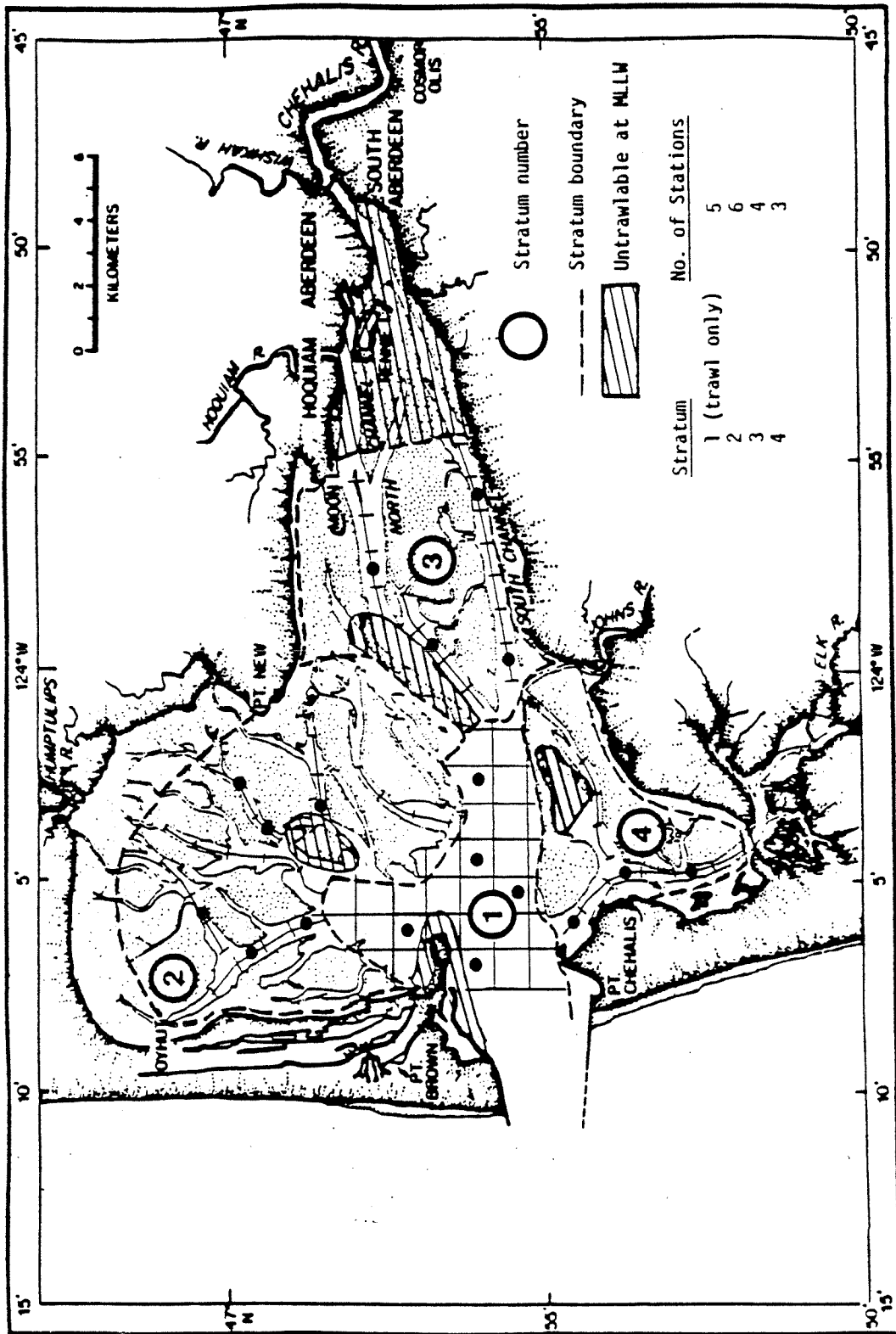


Figure 3. Survey design for the Sea Grant Coastal Crab Project in Grays Harbor. Dots indicate trawl stations, circled numbers designate sampling strata outlined with dashed lines.

using the BIOMASS program on the Burroughs 7800 at the National Marine Fishery Service in Seattle. Regression statistics were computed using the MINITAB package on a VAX computer.

RESULTS AND DISCUSSION

TRAWL CATCH

A total of 42 trawls were taken, capturing 2637 crab (Table 1). Average density at the 5 stations ranged from 502 crab·ha⁻¹ to 1530 crab·ha⁻¹ (Table 2). Overall, crab densities were quite similar to those found at corresponding stations in August 1986 (Dinnel et al. 1986b) and August 1987 (Dumbauld et al. 1988).

Size distributions of the trawl-caught crab are shown in Figures 4 and 5. The 1989 year class (young-of-the-year or 0+, 14-43 mm carapace width) is easily distinguishable in these distributions, but older age groups are well blended. The 0+ age group comprised an average of 14% of the trawl-caught crab (Table 3). Station 3.5 differed from the other four stations in that it was dominated by 0+ crab (57%), which may be due to substrate differences (silt and mud here compared to sand at the other stations) and the proximity of this station to intertidal nursery areas or both. The sex ratio of trawl-caught crab was 70% male to 30% female, with no substantial differences among the stations (Table 4). This ratio is not unexpected, because adult females are believed to migrate out of the estuary at an earlier age than males (Armstrong et al. 1987). Size, sex, and age distributions will be discussed further below in comparison with entrainment data.

DREDGE ENTRAINMENT

Entrainment rates at the 5 stations ranged from 40 crab·kcy⁻¹ (49 crab·ha⁻¹) at Station 3.5 to 325 crab·kcy⁻¹ (352 crab·ha⁻¹) at Station 1.5 (Table 5). A total of 252 crab were caught in dredge samples; the least number caught was at Station 3.5 (10 crab) and the most at Station 1.5 (106 crab). The lower number of crab caught at Station 3.5 was probably due to the increased proportion of silt and organic debris present at that station, which crab tend to avoid.

The overall average sizes of males and females entrained were 84 mm and 91 mm respectively (Table 4). Most of the stations showed similar sizes, but crab at Station 3.5 were noticeably smaller. Many of the damaged crab (condition 3) could not be sexed. The measurable damaged crab had a mean size of 102 mm, which is consistent with previous findings that larger crab are more susceptible to injury by the pump mechanism on the dredge than smaller crab.

Of all crab entrained by the dredge, only 146 (58%) could be sexed (Table 1); of these, the sex ratio was 68.5% male to 31.5% female. The higher percentage of male crab is consistent with past work showing that mature females usually migrate out of the estuary before their third year

Table 1. Number of crab caught during trawl and entrainment sampling by station and sex. All trawl-caught crab were measured. Unsexed crab in trawl samples are all less than 20 mm CW; those in entrainment samples include small and damaged crab.

Location	Males	Females	Unsexed	Total
<u>Trawl samples</u>				
Sta. 1	156	95	7	258
Sta. 1.5	550	243	3	796
Sta. 2	599	205	0	804
Sta. 3	390	144	1	535
Sta. 3.5	145	98	1	244
Total	1840	785	12	2637
<u>Entrainment samples—Measured crab</u>				
Sta. 1	13	8	5	26
Sta. 1.5	41	20	19	80
Sta. 2	14	3	6	23
Sta. 3	14	5	11	30
Sta. 3.5	3	4	0	7
Total	85	40	41	166
<u>Entrainment samples—Unmeasurable crab</u>				
Sta. 1	2	1	11	14
Sta. 1.5	3	1	22	26
Sta. 2	2	0	11	13
Sta. 3	8	4	18	30
Sta. 3.5	0	0	3	3
Total	15	6	65	86

Table 2. Average density of Dungeness crab estimated from trawl samples at the five stations.

Location	No. of trawls	Mean crab·ha ⁻¹	S.D. crab·ha ⁻¹
Sta. 1	8	625	343
Sta. 1.5	9	1367	1069
Sta. 2	8	1530	783
Sta. 3	9	956	643
Sta. 3.5	8	502	549
Overall	42	1004	728

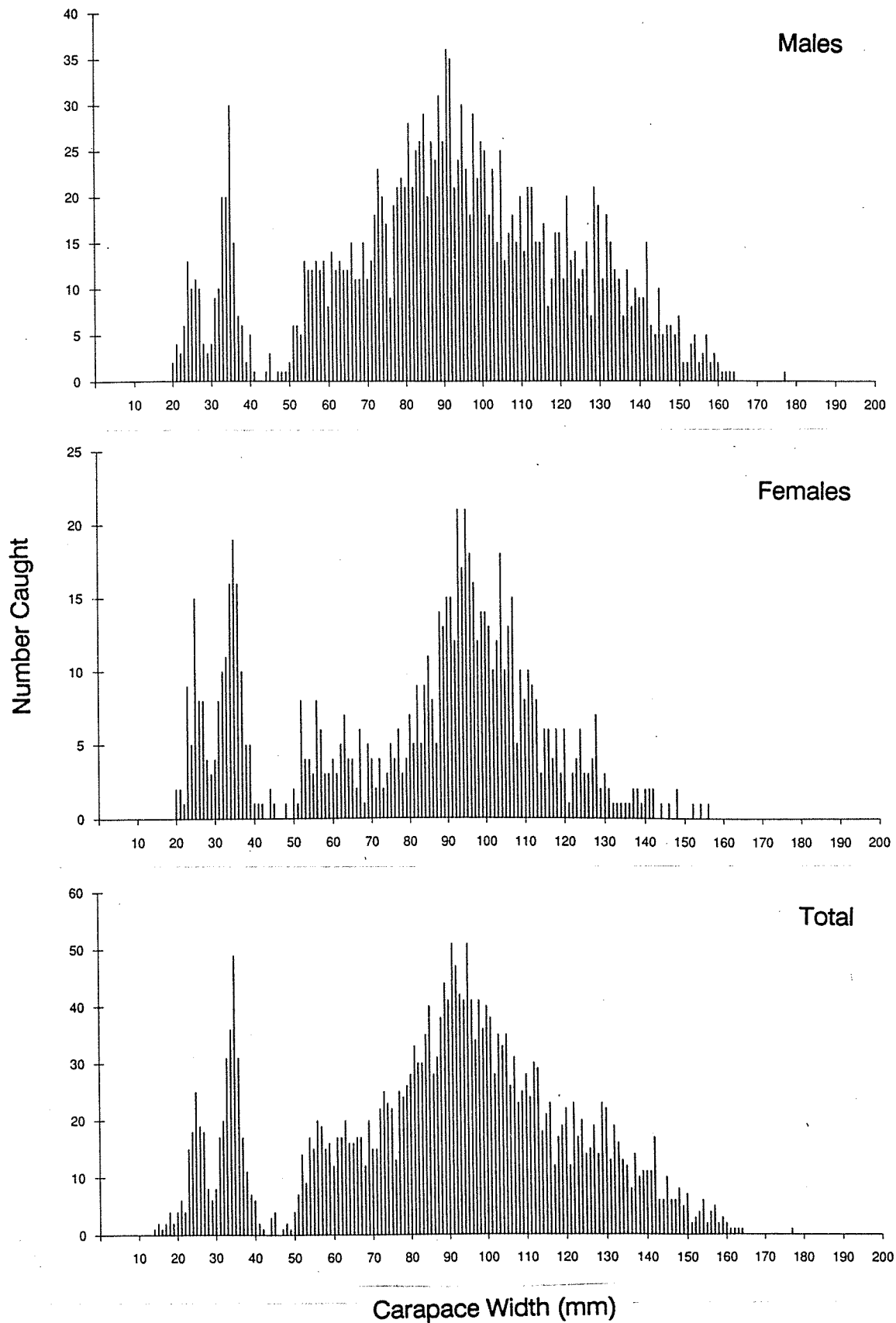


Figure 4. Size frequency distributions for trawl-caught Dungeness crab by 1-mm size intervals, all stations combined. Total includes unsexed crabs below 20 mm.

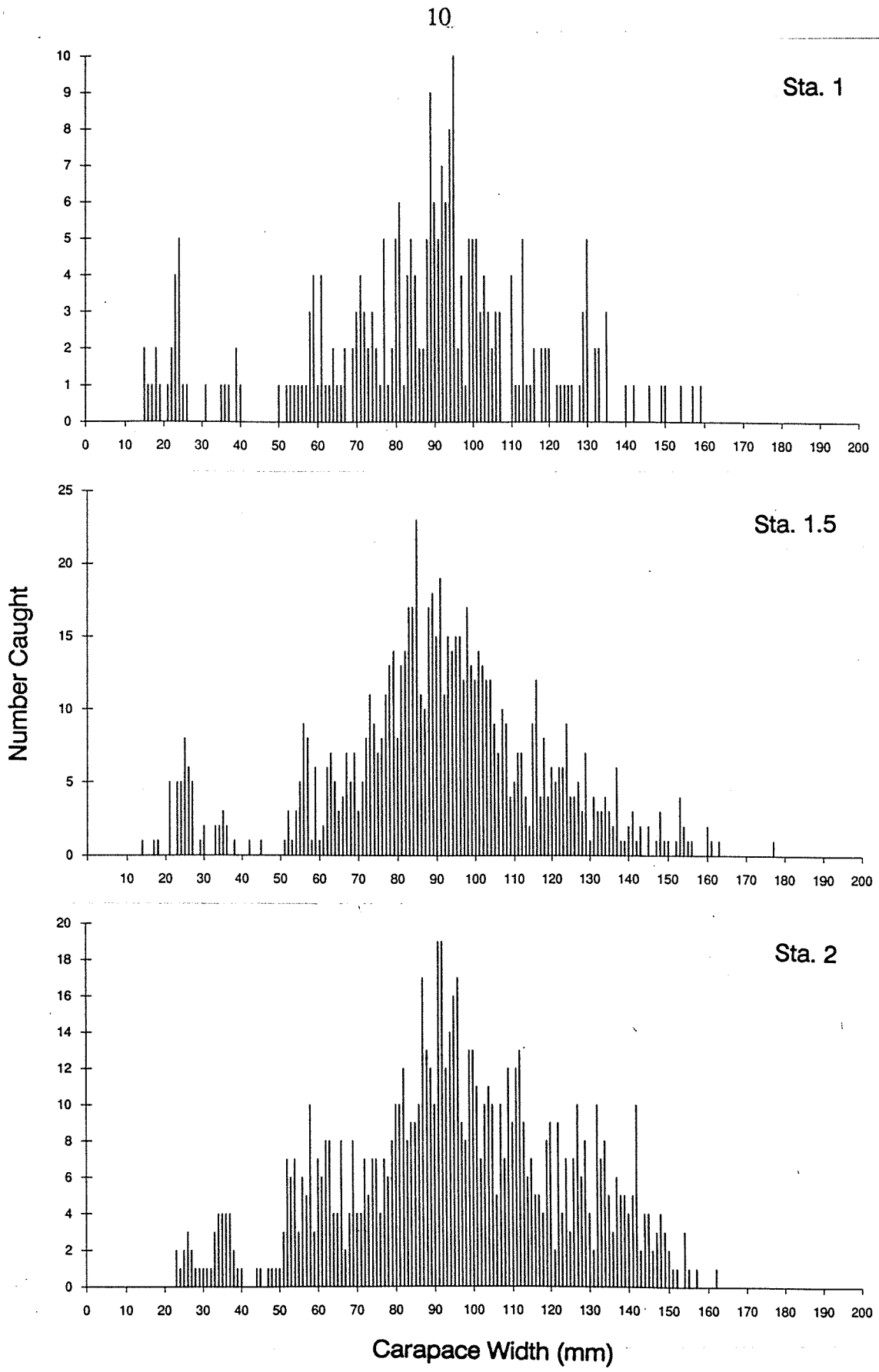


Figure 5. Size frequency distributions for trawl-caught Dungeness crab for each station by 1-mm size intervals, sexes combined.

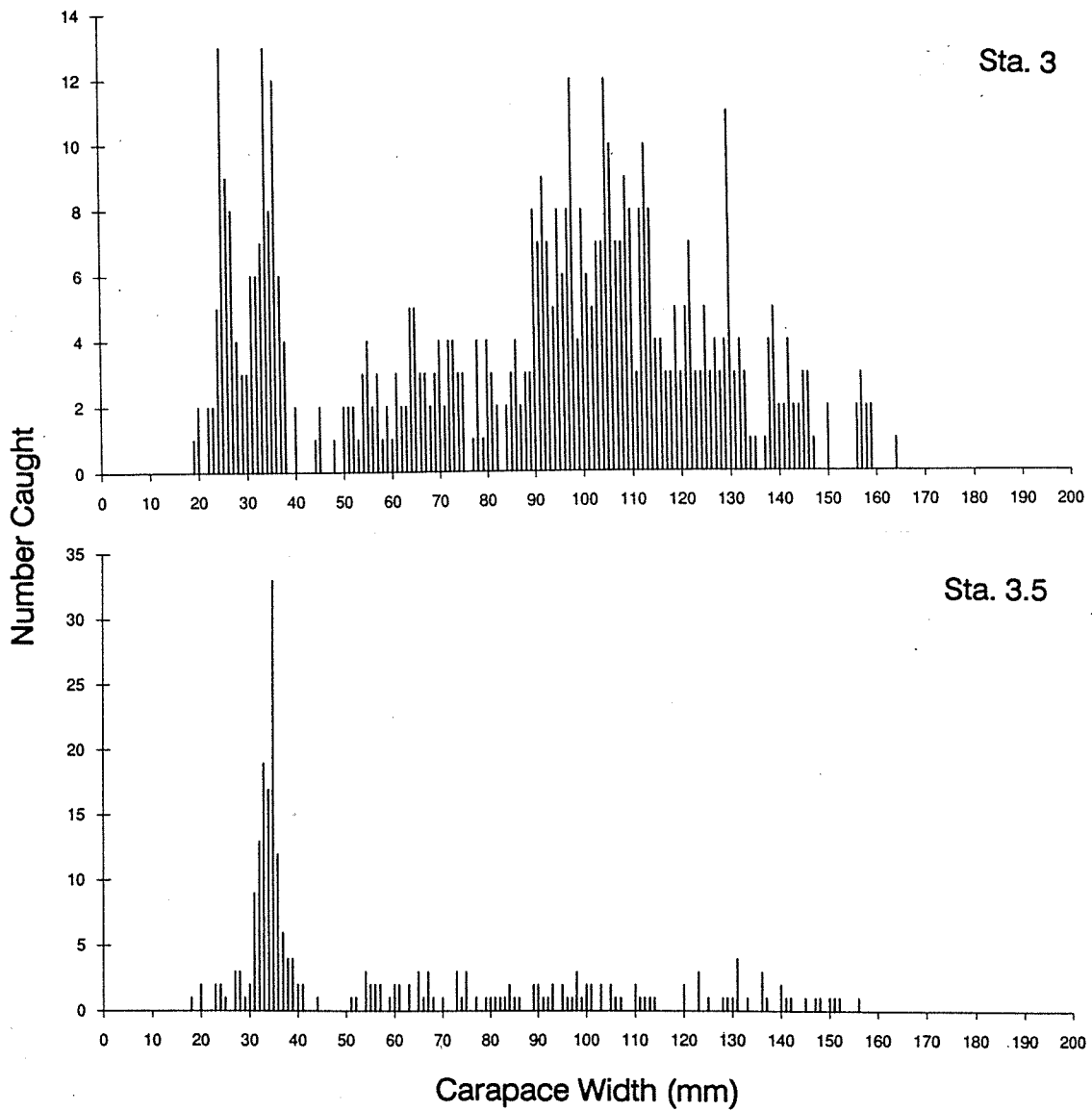


Figure 5. Continued.

Table 3. Percentage of age 0+ crab (less than 44 mm carapace width) in trawl and entrainment samples for the five stations. N is the total number of measured crab in the sample.

Location	Trawl		Dredge	
	N	%0+	N	%0+
Sta. 1	258	10.8	26	15.4
Sta. 1.5	796	6.4	80	18.8
Sta. 2	804	4.7	23	13.0
Sta. 3	535	21.7	30	30.0
Sta. 3.5	244	56.6	7	71.0
Overall	2637	14.1	166	21.7

Table 4. Sex ratios and carapace widths of male and female Dungeness crab in trawl and entrainment samples at the five stations. Crab below 20 mm are excluded from both data sets. Unsexed and unmeasurable (severely damaged) crab are excluded from entrainment data. N is the total number of measured males and females in the sample.

Location	N	M:F(%)	Mean (and SD) carapace width (mm)		
			Females	Males	
<u>Trawl Samples</u>					
Sta. 1	251	62:38	89.4 (25.5)	87.8 (29.6)	
Sta. 1.5	793	69:31	87.3 (28.4)	93.0 (26.4)	
Sta. 2	804	75:25	89.8 (26.1)	97.0 (29.1)	
Sta. 3	534	73:27	72.5 (36.6)	92.3 (35.9)	
Sta. 3.5	243	60:40	55.5 (32.1)	64.2 (39.4)	
Overall	2625	70:30	81.5 (31.8)	91.4 (32.0)	
<u>Entrainment Samples</u>					
Sta. 1	19	58:42	96.6 (34.9)	89.0 (31.2)	
Sta. 1.5	56	70:30	99.5 (35.1)	81.9 (38.3)	
Sta. 2	16	81:19	80.3 (22.9)	101.9 (35.0)	
Sta. 3	18	72:28	90.6 (46.9)	74.1 (44.4)	
Sta. 3.5	7	43:57	49.0 (32.0)	65.7 (42.0)	
Overall	116	68:32	90.7 (35.8)	84.2 (38.1)	

Table 5. Density of Dungeness crab estimated from entrainment samples at the five stations. Number of samples includes both dragheads.

Location	No. of samples	Crab·kcy ⁻¹		Crab·ha ⁻¹	
		Mean	S.D.	Mean	S.D.
Sta. 1	120	220	470	208	311
Sta. 1.5	128	325	500	352	364
Sta. 2	120	115	214	148	212
Sta. 3	100	260	423	322	300
Sta. 3.5	102	40	136	49	108

(Armstrong and Gunderson 1985; Armstrong et al. 1982, 1987; Dinnel et al. 1986a,b). Visual assessment of crab condition showed 23% condition 1, 12% condition 2, and 65% condition 3.

COMPARISON OF DREDGE WITH TRAWL CATCH

Regression of Dredge Entrainment on Trawl Catch

One of the problems in predicting the dredging project impacts on Dungeness crab stocks in Grays Harbor has been estimating the number of crab that would be entrained. In part, this

question can be answered by using a regression relationship to predict the entrainment rate (crab entrained·kcy⁻¹) from trawl-based density estimates (crab·ha⁻¹). This approach was used by Armstrong et al. (1987) and McGraw et al. (1988). With this year's study, we now have 14 data points (Table 6) on which to base the regression.

As is discussed below, several regression models were tried. Of these, the best model was a straight line through the origin, fitted by excluding two statistical outliers from the data. The equation for this model was

$$Y = 0.27X,$$

where Y is entrainment by the dredge (crab·kcy⁻¹), and X is trawl-estimated density (crab·ha⁻¹).

In fitting statistical models to data, the best approach is to start with a simple model and assess its adequacy of fit. Biological reasoning would tell us that entrainment would be expected to rise as crab density rises. With a data set of 14 points, a linear model is still the best place to start: a graph of the data (Figure 6) reveals no obvious higher-order relationships. The computer package MINITAB offers a test (called XLOF) for linearity. This test recomputes the regression in two ways: first by splitting the data into two parts and fitting separate lines to each part, second by fitting a line to just the central region of the data. A large difference between either of these models

Table 6. Mean trawl catch (crab·ha⁻¹) and entrainment by dredge (crab·kcy⁻¹) for 14 station-time combinations used as a basis for predicting entrainment. Data from Dinnel et al. (1986a,b), McGraw et al. (1988), Dumbauld et al. (1988), and this report.

Study date	Station	Trawl catch (crab·ha ⁻¹)	Entrainment (crab·kcy ⁻¹)
10/85	2	506	46
	2	773	118
8/86	1	816	155
	2	1413	500
	4	639	58
8/87	1	504	222
	1.5	972	397
	2	1561	133
	3	968	224
8/89	1	625	220
	1.5	1367	325
	2	1530	115
	3	956	260
	3.5	502	40

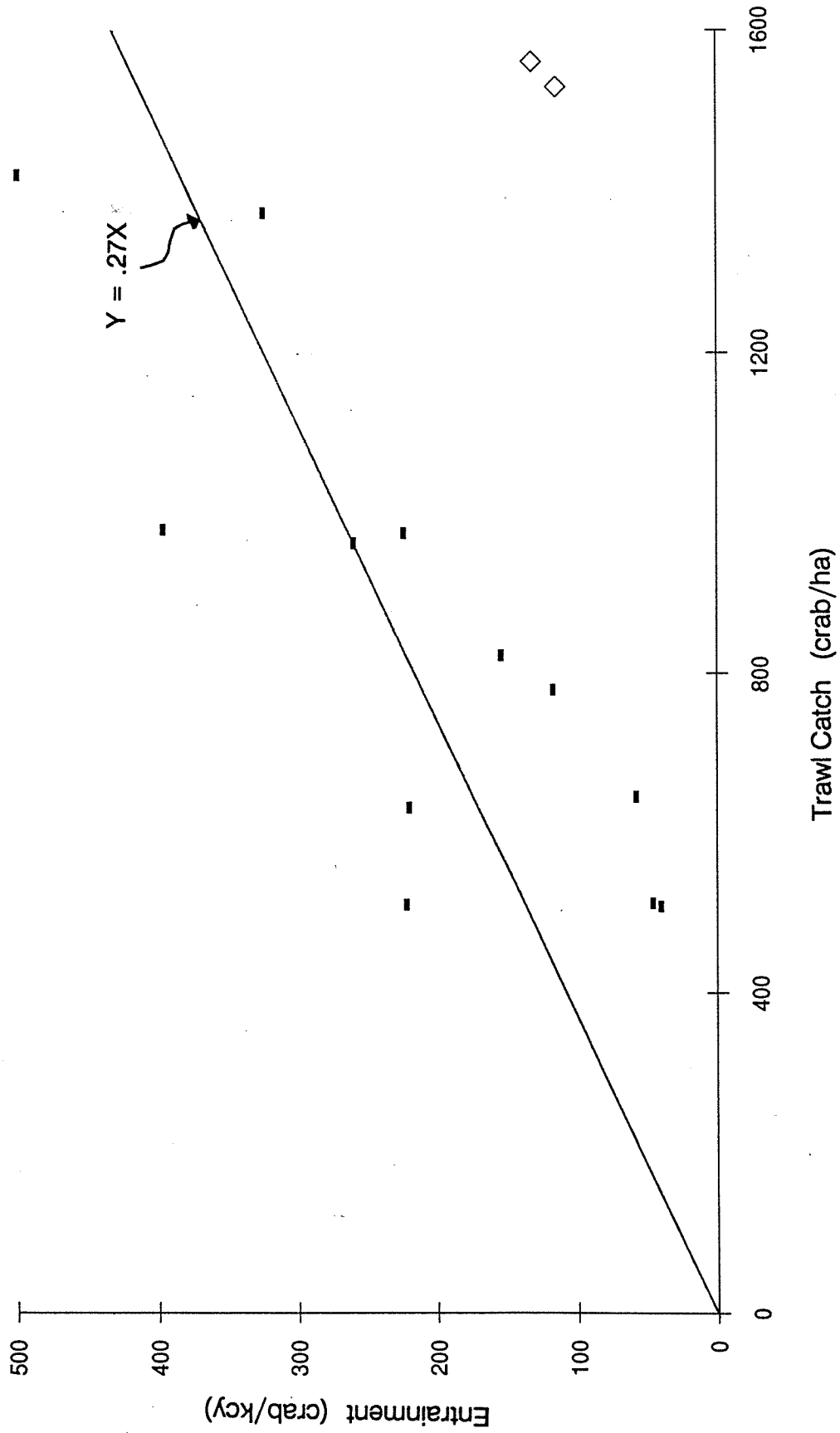


Figure 6. Relationship between entrainment and trawl catch, showing fitted regression line. Diamonds indicate statistical outliers excluded from the standard regression.

and the original model indicates lack of linear fit. The results of these two tests are then combined to give an overall significance level. In this case the P-value was greater than 0.10, indicating “no evidence for significant lack of fit from a linear model.”

Among the 14 data points, two “stand out” because they have been flagged by certain statistical measures used in linear regression diagnostics. These are the points (1561, 133) and (1530, 115), both of which come from Station 2 (see Table 6). They are noted as points which are very “influential” in determining the fitted line, through a computed score known as “Cook's Distance Measure” (Weisberg 1985, pp. 118-125). This procedure studies the effect of each individual point by comparing the full data analysis to the results obtained with each point removed, one at a time.

If the two influential data points are included, the estimated equation is

$$Y = 58.91 + 0.15X.$$

However, neither the intercept nor the slope are significantly different from zero; $r^2 = 0.19$; and the best estimate for the average amount dredged is zero, no matter what the local crab density is, which makes little biological sense.

Upon recomputing the line without these data points, we find that the correlation coefficient increases appreciably from $r=0.432$ to $r=0.82$ (r^2 increases from 0.19 to 0.67). The estimated slope is 0.37 and the computed intercept is -97.7, but the intercept is not significantly different from zero. If we again recompute the line through the origin we obtain the equation

$$Y = 0.27X.$$

Also, a nonparametric regression technique based on an estimated median slope gives a point estimate for the slope of 0.27 when all 14 data points are used. Nonparametric regression is not as sensitive to influential data points as is the usual parametric ordinary least squares regression. For these reasons, a line through the origin with a slope of 0.27 is the most reasonable model for this data set.

This regression has important implications for project mitigation efforts, which are based on total entrainment estimates calculated using this regression relationship. Previously calculated impact predictions used a slope of 0.21 for this relationship, based on entrainment data for 1985-1987 (McGraw et al. 1988). The addition of the data reported here has increased the predicted slope to 0.27, an increase of about 30%. The new slope will be used in conjunction with trawl samples taken during project construction to estimate loss of crab more accurately. These final estimates will, in turn, be used to plan final mitigation (U.S. Army Corps of Engineers 1988, Appendix F).

Comparison of Sex, Size, and Age Composition

Sex composition of the trawl and dredge samples was quite similar (Table 4), with an overall M to F ratio of 70 to 30 for trawls and 68 to 32 for dredge samples. Size composition was somewhat different, however, with the dredge tending to catch larger females (mean width 90.7 mm vs. 81.5 mm) and smaller males (84.2 mm vs. 91.4 mm) than the trawl. A comparison of the total size distributions (males, females, and unsexed combined) for the trawl and dredge samples showed that they were significantly different (Kolmogorov-Smirnov two-sample test, 95% confidence level; Conover 1971). Compared with the trawl, dredge samples had a higher abundance of small (<60 mm) crab and fewer large (>90 mm) crab. Similarly, the dredge samples contained a higher proportion of 0+ crab than the trawls (21.7% vs. 14.1%; Table 3). These results may indicate different size selectivity of the two sampling methods, or may be an artifact of sampling effort differences among the stations and small sample sizes on the dredge; dredge sample size distributions are also biased by the high proportion of unmeasurable crab, which tend to be larger than the undamaged, measurable crab.

BACKGROUND POPULATION ESTIMATES

Trawl sampling elsewhere in Grays Harbor indicated crab densities (Table 7) comparable to those observed in the Navigation Channel. The Navigation Channel passes through sampling Strata 1 (725 crab·ha⁻¹) and 3 (813 crab·ha⁻¹); samples within the Navigation Channel indicated slightly higher densities than in the wider area of those strata, but considerably lower density than the north bay (Stratum 2; 2070 crab·ha⁻¹).

The total crab population estimated for Grays Harbor during this survey (assuming 100% gear efficiency) was 9.98 (±3.59) million. Of these, 5.02 million were 0+, which were found predominantly in the inner, shallower portions of the harbor (Strata 2, 3, and 4), with predominantly older crab in the deeper outer harbor channels (Stratum 1). This agrees with the predominance of older crab found in trawl samples from the Navigation Channel.

Table 7. Grays Harbor population estimates based on trawl samples from Sea Grant stations. Strata are shown in Figure 3. 0+ crab include all those less than 44 mm carapace width. Values in parentheses are twice the standard error of the estimate.

Stratum	Area (ha)	Density		Population (millions)			
		No./ha	(2SE)	0+	Older	Total	(2SE)
1	3651	725	(530)	0.35	2.30	2.65	(1.94)
2	2516	2070	(1086)	3.00	2.21	5.21	(2.73)
3	1548	813	(554)	1.09	0.17	1.26	(0.86)
4	830	1035	(1149)	0.58	0.28	0.86	(0.95)
Total				5.02	4.96	9.98	(3.59)

LITERATURE CITED

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